



Andrzej Marczak\*

## OVERVIEW OF COOPERATIVE COMMUNICATION METHODS

### ABSTRACT

The paper presents issues related to the cooperative communication in wireless networks. Cooperative communication involves the use of mobile terminals as relay stations to improve the transmission quality, improve network performance and reduce energy consumption. It is also possible to use several different data transmission standards. The paper presents the methods used to implement cooperative communication. The types of cooperative communication networks are also presented.

Key words:

cooperative communication, mobile terminal, relay station.

### INTRODUCTION

Currently, mobile users can use mobile data services using cellular technology (e.g. LTE, UMTS, EDGE and GPRS) and low-range data transmission systems (e.g. Bluetooth, WIFI,) which enable a wide range of application in the vehicular environment.

Various wireless communication systems also enable cooperative transmission. Cooperative transmission uses terminals as relay stations to reduce power consumption of mobile terminals, resulting in longer operating times. Cooperative transmission can also increase the capacity, data rates and performance of wireless networks. In addition, it can contribute to increasing the transmission coverage

---

\* Gdańsk University of Technology, Faculty of Electronics, Telecommunications and Informatics, G. Narutowicza 11/12 Str., 80-233 Gdańsk, Poland; e-mail: amarczak@eti.pg.gda.pl

area of both mobile networks and ad hoc networks [1]. As a result, the interest in transmitting on networks using the cooperation of various data transmission systems and relay station is steadily increasing. In the case of cooperative wireless transmission, we have to deal with mobile network or ad hoc network, in which users of mobile terminals can improve the quality of service measured, for example bit or block error rate. In this case, each mobile terminal can be both a data source and a relay station for another user's transmission.

An example of cooperative communication is presented in figure 1. In this example, two mobile terminals (T1 and T2) are simultaneously data sources and the relays.

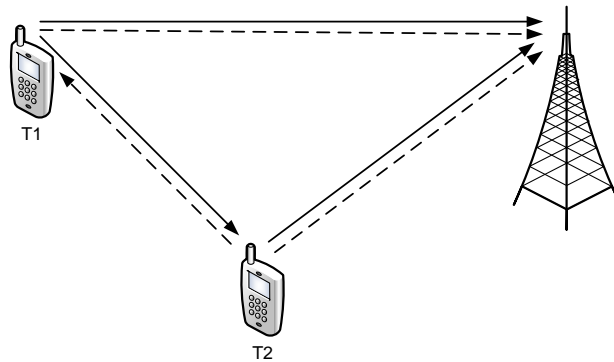


Fig. 1. In case of cooperative communication, each terminal can be both a data source and a relay [3]

## TYPES OF COOPERATIVE COMMUNICATION

For the implementation of the cooperative communication, the three methods are most commonly used: amplify and forward, decode and forward and coded cooperation methods [1, 3].

### Amplify and forward methods

Each terminal in this method receives a noisy version of the signal transmitted by another terminal. According to the method name, the terminal, after receiving the signal from another terminal, amplifies it and then retransmits it (to the destination node of the transmission, e.g. the base station). The destination node combines the signal received directly from the sender and retransmitted by the relay and makes final decision on the transmitted data bits (fig. 2).

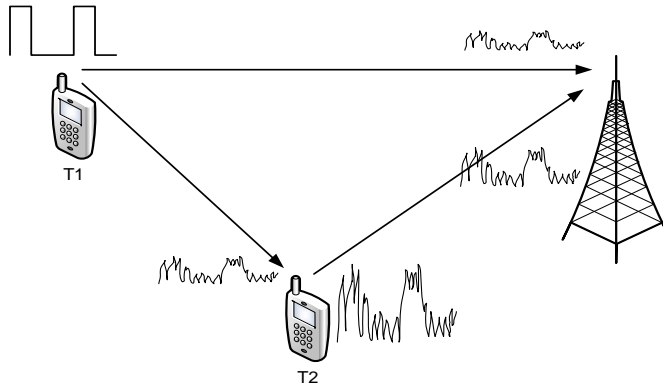


Fig. 2. Amplify and forward method [3]

In this method, the signal is amplified with noise, but the situation that the destination receives two independently faded versions of the signal improves the detection of the information signal, improving the transmission quality. In this method it is assumed that the destination node knows the interuser channel coefficients to do optimal decoding. The mechanism of exchanging or estimating this information must be included into the final implementation [3].

### Decode and forward method

An example of cooperative transmission using the decode and forward method in a CDMA network. In this method, the relay performs the detection and decoding of the received bits from the source and then retransmit those bits to the destination node (fig. 3).

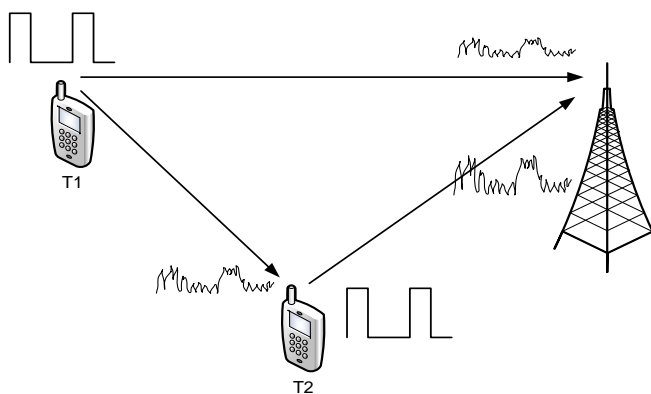


Fig. 3. Decode and forward method [3]

A more detailed description of this method can be found in [4] and [5]. These publications provide an example of an analysis of the use of this method in CDMA transmission. In this example, two terminals are connected with each other to implement cooperative transmission. Each of them has a different spreading code  $c_1(t)$  (terminal 1) and  $c_2(t)$  (terminal 2). Bits transmitted by both terminals can be labeled  $b_i(n)$ , where  $i = 1$  and  $2$  are user numbers,  $n$  is the time index of the transmitted bit. The signals of both the terminals can be saved by the following formulas [4, 5]:

$$X_1(t) = [a_{11}b_1^{(1)}c_1(t), a_{12}b_1^{(2)}c_1(t), a_{13}b_1^{(2)}c_1(t) + a_{14}\hat{b}_2^{(2)}c_2(t)]; \quad (1)$$

$$X_2(t) = [a_{21}b_2^{(1)}c_2(t), a_{22}b_2^{(2)}c_2(t), a_{23}\hat{b}_1^{(2)}c_1(t) + a_{24}b_2^{(2)}c_2(t)]. \quad (2)$$

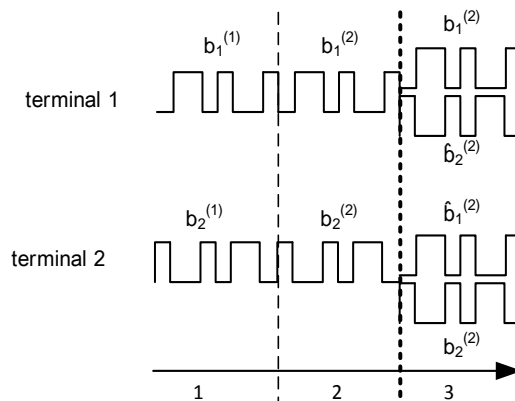


Fig. 4. An example of cooperative transmission using the decode and forward method in a CDMA network [5]

The  $a_{ij}$  coefficients in the formulas represent the amplitude of the signal. The signals  $X_1(t)$  and  $X_2(t)$  have a duration of three bits. Looking at formulas (1) and (2) we can say that during the first and second bits, each terminal transmits its own bits. They then detect the second bit, another user. The bit estimate of this user is denoted by the symbol  $\hat{b}_i$ . During the third bit, a linear combination of its own second bit and a second bit of another user is transmitted over the terminal (fig. 4).

### Coded cooperation

If we assume that the wireless system uses a rate  $R$  channel code, the idea of coded cooperation is to use the same overall rate for coding and transmission,

however, the coded symbols are rearranged between two users. In this case there will be no need for additional resources [2].

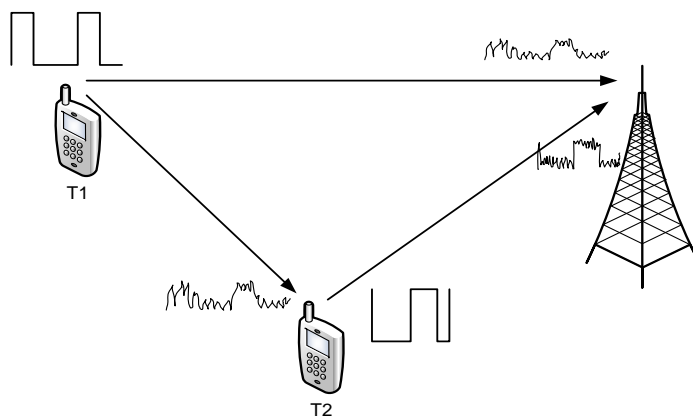


Fig. 5. Coded cooperation [3]

If each user has  $K$  bit data block and  $N$  bit data block after channel encoding, coding rate  $R = K/N$ . We divide the  $N$  bit data block after encoding into two successive time frames, one with length  $N_1$  and the other with length  $N_2$  ( $N_1 + N_2 = N$ ). In the first frame, the code rate is  $R = K/N_1$  [3]. These data (frame) is broadcast by the user terminal and is received by the second terminal and the base station (destination node) (fig. 5). Each terminal will thus receive a noisy version of the coded information from the second terminal in the network. If the terminal 1 can correctly decode the information sent by the second terminal (using e.g. CRC coding) may send the data frame in a time slot  $N_2$  (fig. 6).

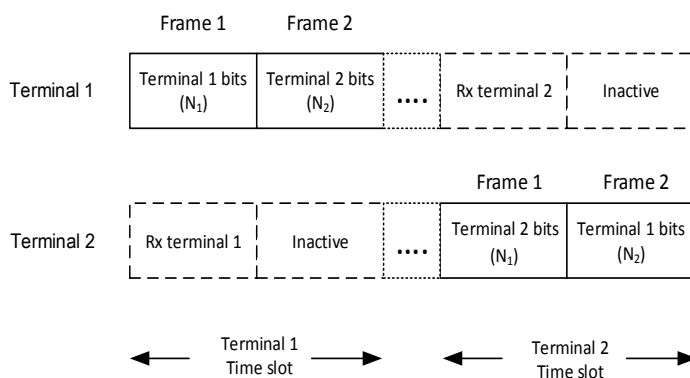


Fig. 6. An example of coded cooperation in a TDMA network [4]

If the terminal cannot correctly decode the data from the second terminal, then its own data is sent in frame  $N_2$ . Each terminal always transmits a total  $N$  bits per source block over the two frames. The overall code in this method may be block, convolutional or turbo code. The code bits for the two frames may be partitioned e.g. through puncturing [1]. Both terminals transmit data independently, without knowing whether their own first frame has been correctly decoded. As a result, there may be four cases shown in figure 7 [4]. In the first case, both terminals correctly receive and decode the transmitted data, so they can send their neighbor's data in the second frame of their time slot. So this is a scenario full cooperative transmission. In the second case, none of the terminal does not receive and decode the data of your neighbor. Each terminal transmits only its data (bits  $N_1$  and  $N_2$ ).

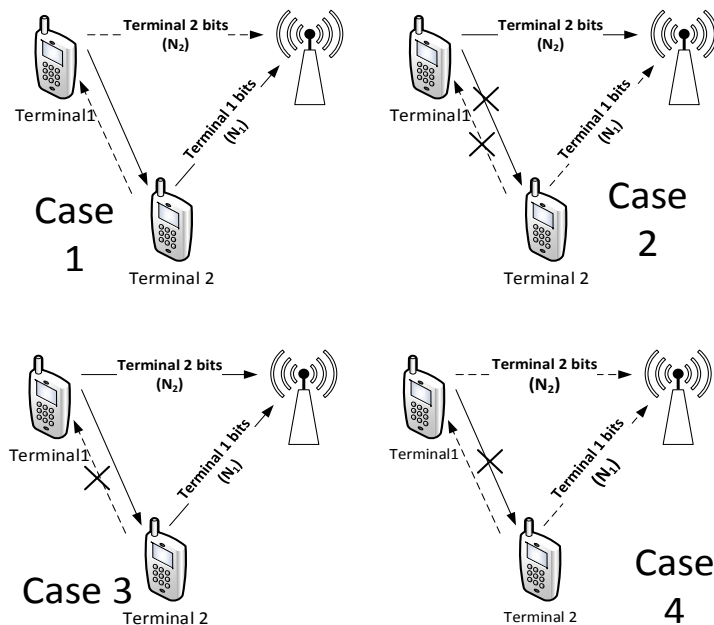


Fig. 7. Four cooperative cases for second frame transmission based on the first frame decoding results [4]

In the third case, terminal 2 correctly receives and decodes data from terminal 1, but terminal 1 does not decode data from terminal 2. In this situation, there is no transmission of bits  $N_2$  of terminal 2, and both terminals (1 and 2) transmit  $N_2$  bits from terminal 1. In the fourth case,  $N_2$  bits of terminal 2 are correctly received and decoded. Terminal 2 has not decoded  $N_2$  bits sent by terminal 1. In this case,

both terminals in the second frame transmit  $N_2$  bits of terminal 2. A destination node to which both terminals send the data needs to know which of the four cases described took place, to be able to correctly decode the received data bits. One way is to check all 4 cases one by one until CRC decodes properly. Another method is to add one extra bit to the data transmitted by the terminal. This bit can indicate the state of the terminal i.e. whether it transmits only its data or data of the other terminal [4].

### COOPERATIVE COMMUNICATION NETWORKS

In cooperative networks may be single relay (fig. 8) or multiple relays (fig. 9). In a single relay network, the data source terminal has only one option to relay its information to the desired destination.

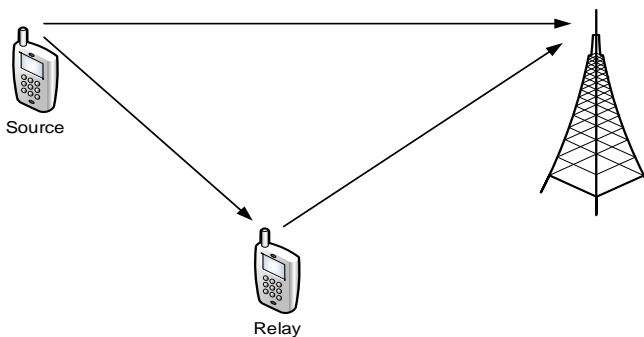


Fig. 8. Single relay cooperation [7]

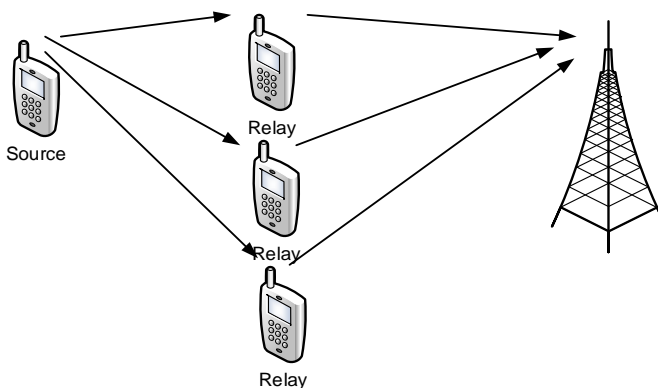


Fig. 9. Multiple relay cooperation [7]

In a network with multiple relays, the data source terminal has more than one relay available as option to forward its data to the destination node (fig. 9) [6]. If the network is decentralized, the terminal can independently select a relay that will retransmit the data to the destination node. In the case of a centralized network, the root node (e.g. base station, router) can help the terminal select a relay that will provide the most effective transmission. Cooperative networks can use single radio access technology or multiple radio access technologies for data transmission. When using only one transmission standard, both the data source and the relay use the same wireless transmission standard (Fig. 10). An example of such a network may be an ad hoc network.

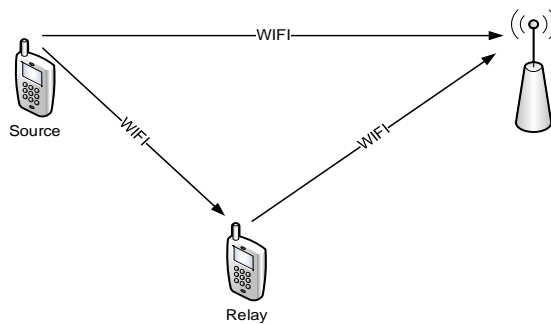


Fig. 10. Single radio access technology cooperation [1]

When using multiple transmission standards for the cooperative transmission, the data source terminal may send data using one wireless standard, while the relay can send the data to the destination node using a different wireless transmission standard (fig. 11).

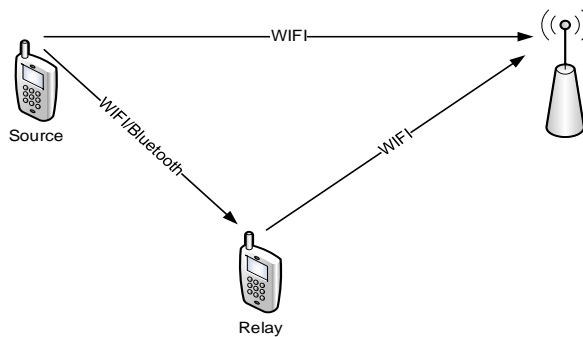


Fig. 11. Multiple radio access technologies cooperation [8]



## CONCLUSIONS

Cooperative communication based on relay transmission is intended for use in 5G networks, particularly in 'green' networks with high energy efficiency [9] and vehicular networks. The use of cooperative communication allows you to reduce energy consumption, thus extending the working time of mobile devices. In addition, it is possible to improve the quality of transmission and to ensure high data rates by using several different wireless data standards. Presented in the paper, methods of implementation of cooperative communication have varying degrees of sophistication and complexity. It can be assumed that one of the ways to ensure the 5G network parameters previously not available in the previous generation radio communication networks, will be the application of cooperative communication.

## REFERENCES

- [1] Alam M., Trapps P., Mumtaz S., Rodriguez J., *Context-aware cooperative testbed for energy analysis in beyond 4G networks*, 'Telecommunication Systems', 2017, 64 (2), pp. 225–244.
- [2] Hunter T., Nosratinia A., *Diversity through Coded Cooperation*, 'IEEE Transactions on Wireless Communications', 2006, 5 (2), pp. 283–289.
- [3] Nosratinia A., Hunter T., Hedayat A., *Cooperative communication in wireless networks*, 'IEEE Communications Magazine', 2004, 42 (10), pp. 74–80.
- [4] Sendonaris A., Erkip E., Aazhang B., *User cooperation diversity, Part I, System Description*, 'IEEE Transactions on Communications', 2003, 51 (11), pp. 1927–1938.
- [5] Sendonaris A., Erkip E., Aazhang B., *User cooperation diversity, Part II, Implementation aspects and performance analysis*, 'IEEE Transactions on Communications', 2003, 51 (11), pp. 1939–1948.
- [6] Larsson P., *Large-scale cooperative relaying network with optimal coherent combining under aggregate relay power constraints*, WWRP: New Air Interfaces, Relay based Systems and Smart Antennas, 2004.
- [7] Laneman J., Wornell G., *Energy-efficient antenna sharing and relaying for wireless networks*, 'IEEE Wireless Communications and Networking Conference', 2000, 1, pp. 7–12.
- [8] Navaratnarajah S., Saeed A., Dianati M., *Energy efficiency in heterogeneous wireless access networks*, 'IEEE Wireless Communications', 2013, 20 (5), pp. 37–43.
- [9] Nomikos N., Nieto A., Makris P., Skoutas D. N., Vouyioukas D., Rizomiliotis P., Lopez J., Skianis C., *Relay selection for secure 5G green communications*, 'Telecommunication Systems', 2015, 59, (1), pp. 169–187.



# PRZEGLĄD METOD TRANSMISJI KOOPERACYJNEJ

## STRESZCZENIE

W artykule zaprezentowano zagadnienia związane z transmisją kooperacyjną. Polega ona na wykorzystaniu terminali ruchomych jako stacji przekaźnikowych w celu poprawy jakości transmisji i wydajności sieci oraz zmniejszenia zużycia energii. Zaprezentowano metody stosowane do realizacji transmisji kooperacyjnej i przedstawiono wykorzystujące ją rodzaje sieci.

Słowa kluczowe:

transmisja kooperacyjna, terminal ruchomy, przekaźnik.